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Forest resource change detection using high-resolution satellite imagery for monitoring and effectiveness evaluation

by

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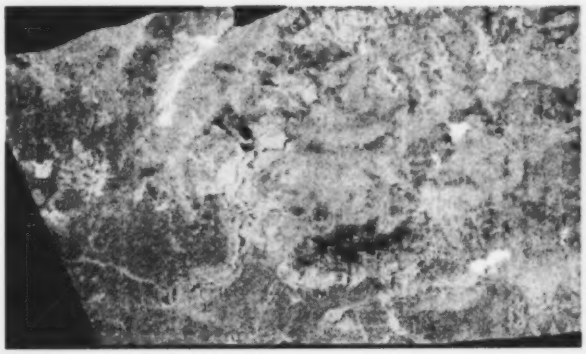

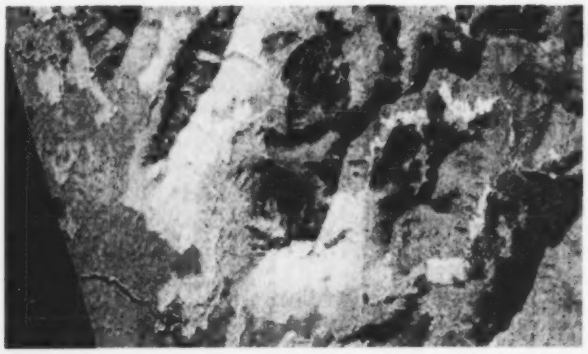

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Cover photo: Change detection map using Ikonos and Quickbird imagery and Quickbird natural colour image of study area.

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SUMMARY

An ongoing remote sensing project has been underway within the Coast Forest Region since 2000. The initial phases of the project studied the uses of new commercially-available high-resolution satellite imagery for the purposes of resource feature mapping and compliance and enforcement surveillance. This report presents a comparative analysis of the Ikonos imagery acquired in 2000 and the newly acquired Quickbird imagery from 2003. This comparative analysis enables the mapping of the spatial extent and magnitude of change over time across the landscape. This analysis is intended to provide some insight into the uses of high-resolution satellite imagery for change detection within a forest resource management context. Changes in harvesting patterns, revegetation, windthrow, road deactivation and landslides are identifiable in the satellite imagery. Subtle changes on the margins of cut blocks or within standing timber are also detectable using this analysis technique, and provide input to Compliance and Enforcement (C&E) risk rating and inspection prioritization.

1.0 INTRODUCTION

Resource managers require an aerial perspective to monitor and manage the resource and its infrastructure. Remote sensing methods have been utilized as a forest management tool for many years (Bergen et al., 2000).

The *Forest and Range Practices Act* and its objectives and regulations establish the rules that govern commercial forestry and range activities on Crown lands, to ensure sustainability for future generations. In addition to the Compliance and Enforcement (C&E) regime, government and industry are committed to effectiveness evaluations to ensure that these legislated requirements and objectives are themselves effective and comprehensive. Therefore, the demand for timely and accurate resource feature information about the distribution, composition and status of landform features is likely to increase. It is envisioned that high-resolution satellite imagery will be one of the tools used by specialists reviewing on-the-ground results against objectives so that government can monitor and improve its policies and objectives, based on scientific data.

In the interests of developing new tools for forest resource management and routine effectiveness evaluation, the use of high-resolution satellite imagery has been the subject of ongoing research in the Coast Forest Region. This project tested the use of high-resolution satellite imagery for the purpose of updating forestry-related changes across the landscape. The project's goal was to develop tools to be used in a long-term, high-quality monitoring and effectiveness evaluation program to identify trends in forest status and to detect changes in forest resource features, including vegetation extent and composition.

Table 1. High-resolution sensors in use for terrestrial remote sensing studies.

Satellite	Temporal Resolution	Ground Swath	Spatial Resolution
Landsat7 ETM	16 days	185 km	15 x 15 m (ETM8), 30 x 30 m (TM 1-5, 7), 60 x 60 m (TM 6HL)
Spot-5	26 days	117 km	10 x 10 m (MLA), 5 x 5 m (PLA), 2.5 x 2.5 m (PLA)
Ikonos	3-11 days	13 km	4 x 4m multi, 1 x 1m pan
Quickbird	1-3 days	16.5 km	2.44 x 2.44m multi, 0.61 x 0.61m pan

The methods to be used in the forest resource evaluation program include routine, extensive and intensive levels of evaluation. Landsat Thematic Mapper (TM), Satellite Pour l'Observation de la Terre (SPOT), and other satellites with imagery in the 10-30m resolution range (Table 1) have been used for change detection purposes for many years, for different types of land use and at different scales (Civco et al., 2002). However, it is envisioned that the use of high-resolution satellite imagery from state-of-the-art commercial satellites such as Ikonos and Quickbird can contribute to monitoring and evaluating down to small-scale indicators, and can be used for the planning of both the routine and extensive levels of evaluation. The availability of high-resolution satellite imagery has provided new tools for use in forest resource management. For example, Carleer and Wolff (2004) have used Ikonos satellite imagery to research the potential of such imagery for forest type mapping and age class delineation.

To enable satellite imagery from multi-date periods to be used for change detection, the imagery must be co-registered (through orthorectification) and radiometrically corrected. This ensures that changes due to misregistration are minimized and that pixels from the same features on each site correspond on the co-registered image. For the current project, this process was conducted by McElhanney Consulting Services Ltd. The change detection method used included the generation of a landscape-scale change map that provided a suite of change classes. These were then quantified and followed up by cross checking with other data and ground truthing (on-ground verification). In addition to the change detection component, cluster analysis was also conducted in an attempt to classify the different ground cover components across the various images.

KEYWORDS

Remote sensing, Ikonos, Quickbird, change detection, effectiveness evaluation, forest resource management

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Interpreting the causes of a change was conducted by visually analysing the change map and applying local knowledge of the area. Foresters from the licensee operating in the area were engaged to review the imagery to assist in the interpretation of the change detection map, as were Compliance and Enforcement staff. Areas of interest for on-ground review and inspection were subsequently chosen using the above process. Despite the high spatial resolution of the imagery, which allows for the identification and delineation of small-scale structures, there are issues regarding the interpretation of change detection imagery due to differences in off-nadir viewing angles and solar illumination at the time of data acquisition. These variations – an issue that has also been noted in other studies (e.g., Niemeyer and Canty, 2003) – can produce differences in shadow patterns that result in false change detection or mask areas of real change.

2.0 METHODOLOGY

2.1 STUDY AREA

This change detection project was conducted in the Hesquiat/Escalante/Mooyah areas, located within and adjacent to Clayoquot Sound on the west coast of Vancouver Island (Figures 1 and 2). The area is within the South Island Forest District of the Coast Forest Region.

This area was chosen due to the significant amount of pre-existing digital and on-ground data available for it. In addition, in a previous project (Collins et al., 2001), the authors conducted an analysis of the northern section of this area using high-resolution Ikonos satellite imagery. Part of the current project is to determine change between the Ikonos and Quickbird images, which were acquired approximately three years apart (Figure 3).

Figure 2. Quickbird coverage of Hesquiat/Mooyah area. Note the two scenes are mosaicked together for complete coverage.

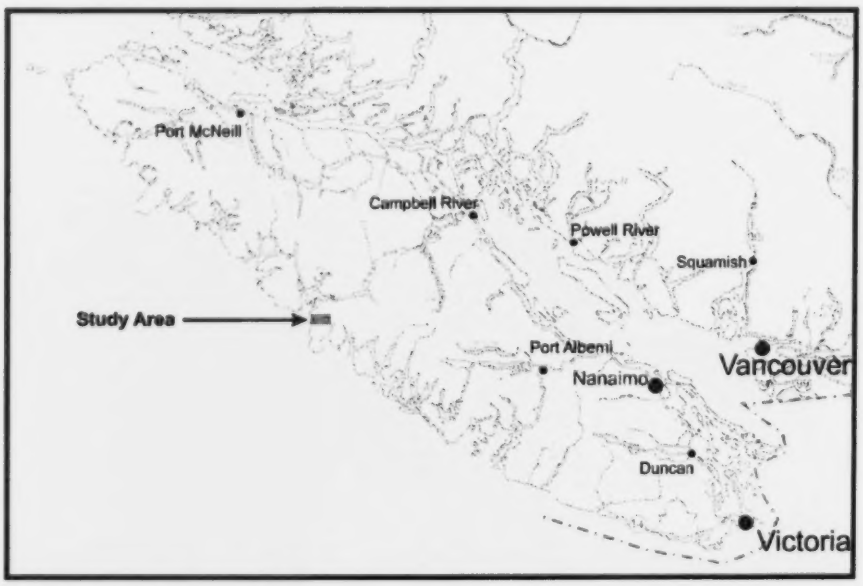

Figure 1. Study area location on Vancouver Island.

The area's topography ranges from flat to steep-sided terrain, with elevations ranging from sea level along the coastal plain north of the Estevan Peninsula, to approximately 1000 m inland. The flats, known as the Estevan Coastal Plain, extend inland for about 6 km from the mouth of the Escalante River and encompass the Hesquiat Peninsula. Much of the area was logged in the 1960s and into the 1980s, but some recent variable retention logging has been conducted. There are numerous landslides in the area, pre-dating the introduction of the Forest Practices Code (FPC). Some of these are natural landslides (Lewis and Liard, 1983), and many occurred during an intense storm cycle in January 1996.

The area is predominantly underlain by granitoid rocks of the Island Intrusions and Westcoast complex (Muller, 1977). Conglomerates and sandstone of the early Tertiary Escalante Group underlie part of the area, and similar lithologies of the Carmanah Group outcrop in the Hesquiat Lake area. In the north fork of the Escalante watershed, Karmutsen Volcanics outcrop and the bedrock is metamorphosed and intensely sheared. This, combined with high rainfall and freeze-thaw processes, has produced a highly fractured and friable bedrock, which in turn has resulted in the formation of deep colluvial blankets on many of the steep hillsides. Structurally controlled valleys have been glacially deepened and widened, a legacy of Quaternary glaciation. Preferential erosion along faults and other structural lineaments has created tributary valleys and deeply incised gully systems. Deep silty to gravelly tills, stratified gravelly glaciofluvial deposits, and laminated silts are present in the lower valley slopes.

The west coast weather of Vancouver Island is dominated by Pacific cyclones that cause significant cloud cover and precipitation. The area is situated within the transition between the very humid and the very wet maritime Coastal Western Hemlock biogeoclimatic zones (CWHvh and CWHvm). Predominant conifer species consist of western redcedar (Thuja plicata), western hemlock (Tsuga heterophylla) and amabalis fir (Abies amabilis). Many of the older landslides have been revegetated by red alder (Alnus rubra).

2.2 QUICKBIRD SATELLITE

Quickbird-2 was launched on October 18, 2001, and orbits approximately 450km above the earth. It is part of a new generation of satellites collecting very high-resolution optical image data. Quickbird has a 0.61 metre resolution panchromatic sensor and a 2.44 metre resolution multispectral sensor. This is the highest ground resolution satellite currently available to the public and is comparable to the resolution of some aerial photography (Table 2).

Figure 3. Area of overlap between the Quickbird and Ikonos images used for change detection.

The Quickbird satellite is operated by DigitalGlobe (formerly EarthWatch Incorporated) of Longmont, Colorado. Through a combination of different multispectral image channels, Quickbird imagery provides a natural colour image, and a false colour infrared image that can be interpreted visually. The im-

Table 2. Quickbird-2 specifications.

Product Name	Spatial Resolution at Nadir	Spectral Bands (Micrometers)	Dynamic Range
Quickbird Multispectral	2.44 meter	Band 1: 0.45 - 0.52 (Blue) Band 2: 0.52 - 0.60 (Green) Band 3: 0.63 - 0.69 (Red) Band 4: 0.76 - 0.90 (Near Infrared)	11 Bit (2048 levels)
Quickbird Panchromatic	0.61 meter	Pan Band: 0.45 - 0.90	11 Bit (2048 levels)

ages are available in 0.61-metre resolution black-and-white and 2.44-metre resolution colour versions. These products are available as 11-bit black-and-white and 11-bit colour, giving users 2,048 shades of grey/colour compared with the traditional 8-bit data, which only provides 256 shades of grey/colour. These additional shades of grey/colour are useful, for example, when viewing features in shadowed areas. Quickbird products are sold by the square kilometre according to customer requirements. Basic (i.e., unprocessed) imagery prices are US $30 per square kilometre for either multispectral or panchromatic imagery, and US $30 plus 50% for a multispectral / panchromatic image bundle. The minimum scene size for basic imagery is 272 km2 (http://www.digitalglobe.com).

2.3 QUICKBIRD-2 DATA ACQUISITION

To order the Quickbird-2 imagery, corner co-ordinates of the area of interest were provided to Radarsat International, a Canadian supplier. The initial search schedule was to acquire an image during August/September 2003. Two Quickbird-2 images were required to provide coverage for the area of interest. The dates of the two images are shown in Table 3.

2.4 DIGITAL IMAGE PROCESSING METHODOLOGY

2.4.1 QUICKBIRD ORTHORECTIFICATION

The first step in the image processing was to orthorectify the satellite images, which was followed by the production of composite images for interpretation. Both images were orthorectified to UTM Zone 10, NAD83 datum. To orthorectify the images, McElhanney used the OrthoWarp ER third-party extension to ER Mapper, which is made by INPHO GmbH (http://www.inpho.de/).

Orthorectification of the Quickbird imagery followed these steps:

1. The Quickbird panchromatic and multispectral images were ingested into OrthoWarp ER;
2. A DEM that covered the area occupied by the Quickbird image was ingested into OrthoWarp ER.
3. Ground control points (GCPs) were identified in the Quickbird image which matched known features in the vector linework (vector linework was loaded into MapInfo Professional GIS and viewed in conjunction with the OrthoWarp ER session; the DEM and some of the vector linework were acquired from Terrain Resource Inventory Mapping (TRIM) data). An attempt was made to evenly distribute the locations of the ground control points across the imagery, as much as possible, so that the entire image could be rectified. The same GCPs that were applied to the panchromatic image were also applied to the multispectral image. Appendix A provides the root mean square (RMS) error for each GCP in the images.
4. The images were then orthocorrected using the DEM. An output pixel size of 0.63 m was produced for the panchromatic imagery, and 2.5m pixel size was produced for the multispectral imagery.

The Quickbird image combinations that were produced were:

a) red, green and blue (RGB) channels with panchromatic image;

b) near infrared, red, green channels with panchromatic image;

c) Guided Principal components image derived from blue, green, red and near infrared channels;

d) Guided Principal components image merged with panchromatic image.

Image combinations a) and b) were enhanced using manual contrast stretching. Figure 4 shows the individual bands as greyscale images, while Figures 5 and 6 show different aspects of image combinations a) and b) for the area of interest.

2.4.2 PRINCIPAL COMPONENT ANALYSIS

One of the digital processing techniques used for this and previous related projects (e.g.. Collins et al., 2001) was Guided Principal Component Analysis (PCA), which is a form of data merging and data compression which reduces the dimensionality or number of bands that the interpreter has to analyse to produce results.

PCA is a statistical technique for compressing the spectral variance in multiple image bands into a subset of principal component (PC) bands, where each PC band is uncorrelated with the others. This means that each PC band provides unique information not contained in the other PC bands. The first PC band (PC1) is basically the average of the input bands' values. The second PC band (PC2) contains the second highest amount of scene variance that is not taken into account by the first PC band. This process continues until the last PC band, which contains the least amount of unique scene variance information. The last PC band usually also contains scene noise. As a result of the concentration of scene variance in the first few PC bands, this reduces the number of image bands that need

Table 3. Quickbird-2 order details.

Order ID	000000080716_01_P001	000000080716_01_P002
Date of acquisition	Sept 04, 2003	Sept 04, 2003
UL co-ordinates	ULLon = -126.56976341; ULLat = 49.64141418;	ULLon = -126.57272831; ULLat = 49.58177930;
Pixel spacing	0.61 m panchromatic / 2.44 m multispectral	0.61 m panchromatic / 2.44 m multispectral

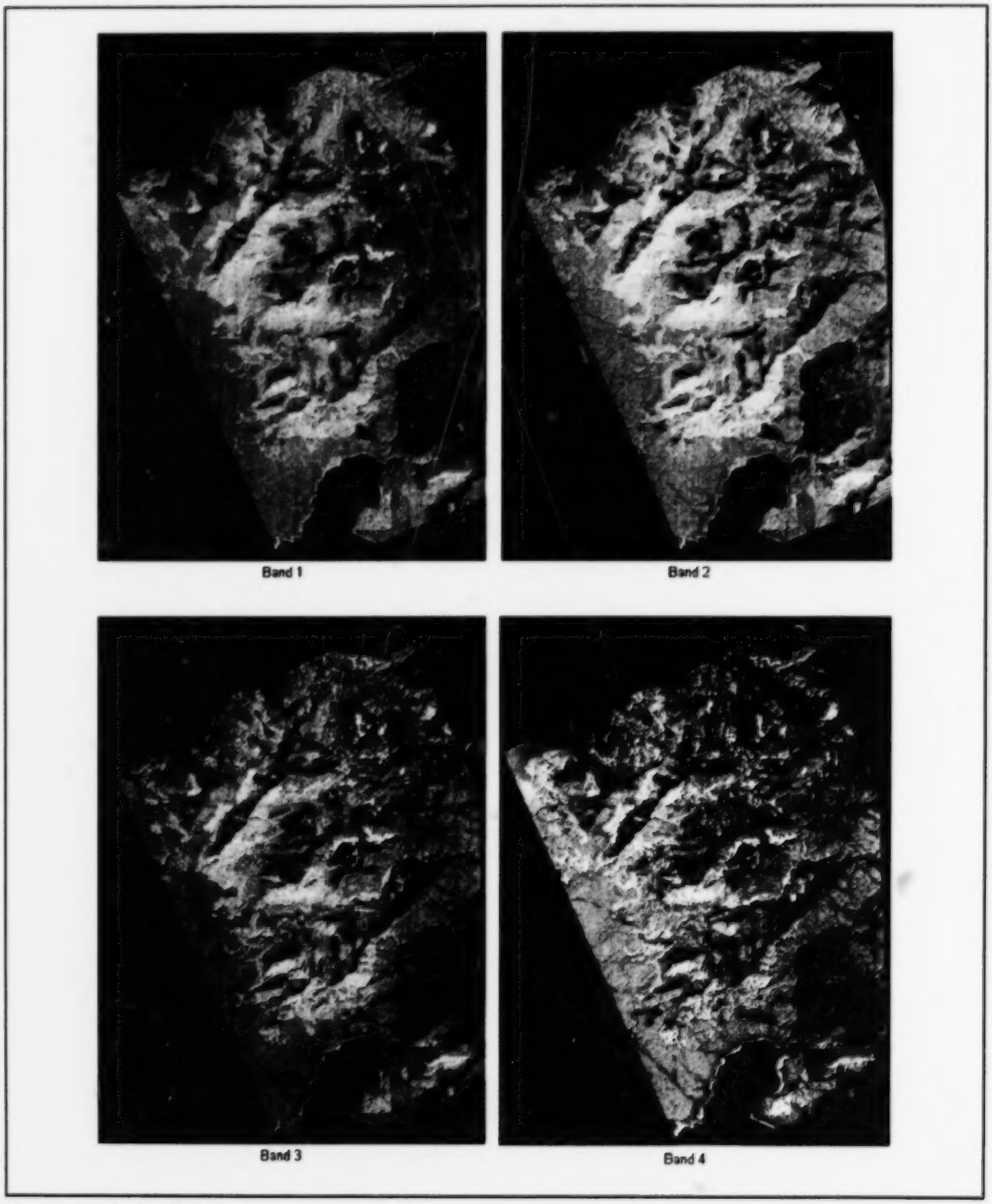

Figure 4. Quickbird individual image bands (greyscale).

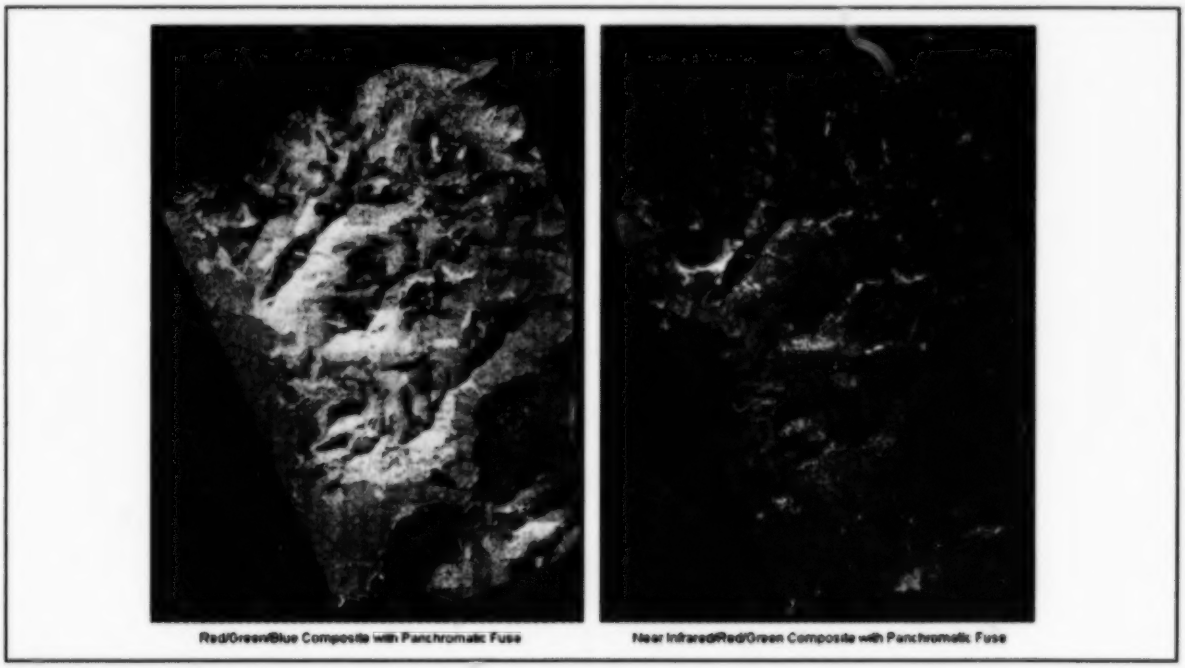

Figure 5. Colour composite panchromatic images.

to be analysed to produce results.

PCA does not achieve the maximum separability of any one feature type, although in general features can become more separable. With guided PCA, a statistical sample area is used to transform the image channels that are defined by the image analyst. In this case, polygons surrounding areas of combined forest and clearcut were digitized. The statistics generated from these polygons should maximize the spectral variation between forest and clearcut features, and potentially allow a more detailed analysis of the forest area and clearcut areas.

The factor loadings from guided PCA were initially reviewed and bands chosen based on having an inverse relationship between the visible and near infrared channels. The bands that have very large positive and very large negative values were also checked, as these could be viewed as pseudo-ratios. The polygons were identified in order to determine whether small variations in the forest or clearcut features could easily be identified.

Figure 6. Example of a portion of the panchromatic image.

The choice of PCA channels to use in an RGB display on the computer screen was decided by reviewing the factor loadings of each PC channel (Table 4). A channel was selected if it had a significantly high positive loading in one band and significantly high negative loading in another band, and if the remaining bands had values near zero, or there was something of interest visually in the PC channel. PC channels of interest have factor loadings in bold.

Figures 7, 8, 9 and 10 show the individual PCA channels as greyscale images and as colour composite images for the study area.

Table 4. Single date statistics for the Quickbird imagery.

Correlation Eigenvectors	PC1		PC3	PC4
Band1-QB-blu	0.56383	**-0.20062**	**0.65558**	-0.46049
Band2-QB-grn	0.57351	0.07057	**-0.72917**	-0.36663
Band3-QB-red	0.5711	**-0.15073**	0.02913	0.8064
Band4-QB-nir	0.16441	**0.96543**	0.19408	0.057

Red: PC1; green: PC2; blue: PC3

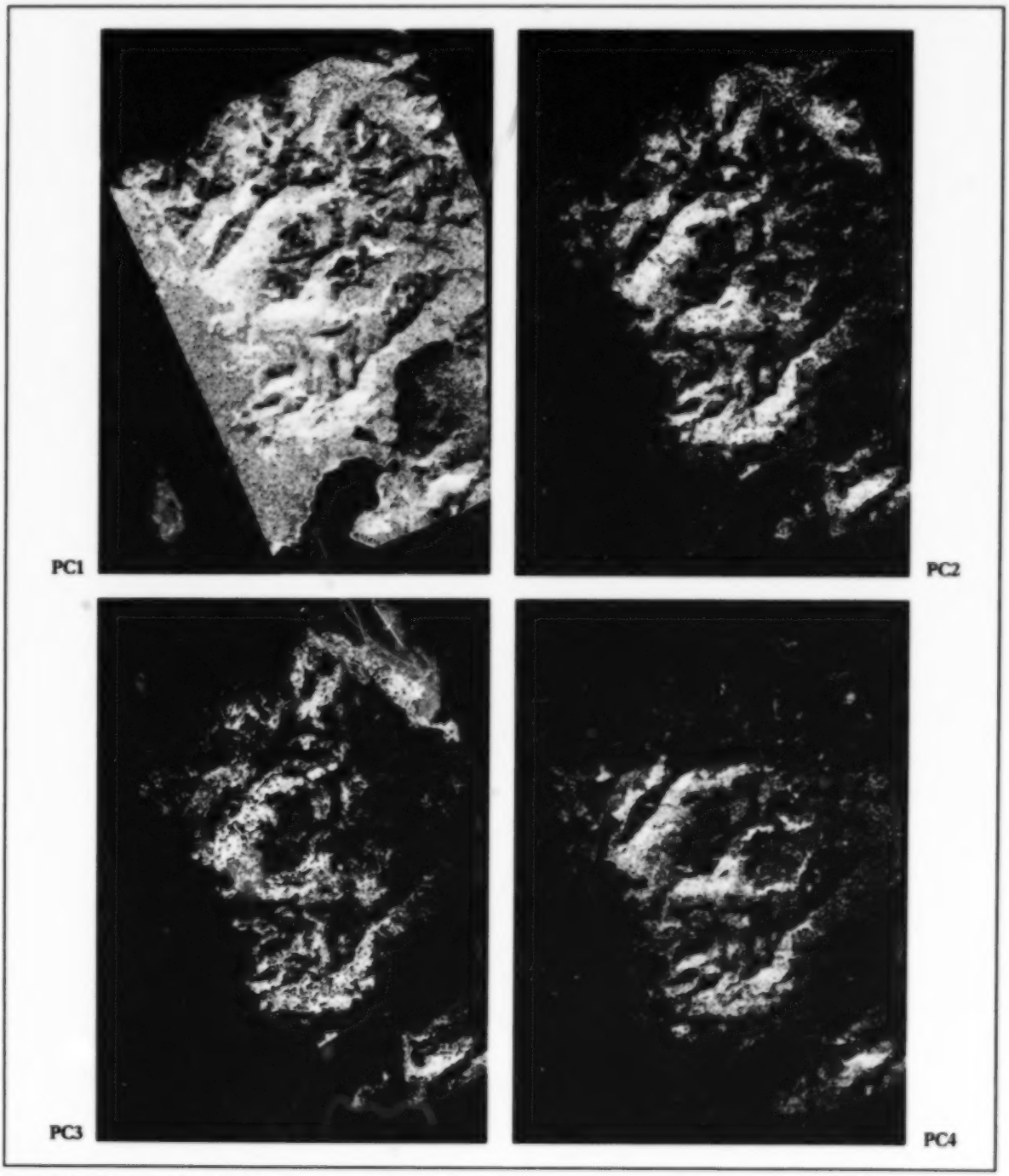

Figure 7. PC channels 1 through 4, shown as greyscale images.

PC1 (Figure 7) is mostly an average of the three visible image channels with a lesser amount contributed by the near infrared channel. It appears similar to a visible image channel. PC2 is primarily the near infrared channel, with some difference with the red and blue channels. This image tends to show treed areas in darker tones, while clearcut and rock/bare soil areas appear as lighter tones. Although an analysis was not undertaken, this image may provide an indication of vegetation vigour.

PC3 is primarily the difference between the blue and green channels, with green negatively weighted and blue positively weighted. PC3 has similar tones to PC2, except that the areas of lighter tones are more concentrated and road networks are more evident. PC4 has an inverse relationship between blue/green as negative loadings and red as a positive loading. This image has generally a middle grey tone. There is less variability evident compared with the other PC image channels. Areas such as the northeast corner show very little difference in tone compared with the other channels. The most difference is seen in some of the bare soil/clearcut areas. This channel was not selected for the colour composite, partly due to its low contrast, but also to avoid dropping PC1, which showed the most detail in the scene, or PC2, which had the ratio between the near infrared and visible light channels.

In the colour composite image (Figure 8), newly cleared forest areas, roads, and slide areas show up in orange tones. Revegetated areas appear in cyan tones. Forested areas are reddish brown. Water bodies appear black. Areas which are occupied by alder appear yellow (see enlarged portion of this image, Figure 9).

Figure 8. PCA colour composite image for the Quickbird single date image.

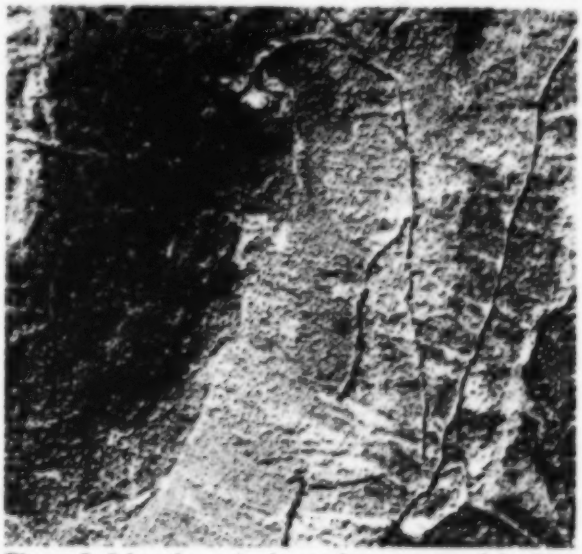

Figure 9. Selected area in the northeast corner of the PCA single date image, showing variable retention harvested area.

However, because of image uniqueness, one cannot use this as a typical characterization of each type of thematic class under consideration.

2.4.3 CLUSTER ANALYSIS

Isoclass cluster analysis was applied to the single date Quickbird images. Table 5 displays the parameters that were used for the cluster analysis.

Isoclass cluster analysis is a multi-pass method which derives stable clusters of pixels theoretically representing relatively homogenous cover types. The process proceeds by initially assigning class mean pixel values for a tentative number of classes (40 classes, in this case). Each pixel in the image is compared with the different class means and is assigned to the class with the smallest distance to the mean value. After all the pixels are assigned, the classes are split or merged depending on split/merge criteria, then the mean for each cluster of pixels is calculated and compared with the initial seed mean value. If the new means move by more than a minimum distance, the pixels from the image are reassigned to the new mean values and the process continues until the means become stable. At that point, each pixel in the image is assigned a class value.

Table 5. Parameters used for isoclass cluster analysis of single date Quickbird images.

Number of classes to generate	40
Maximum number of iterations	25
Percent unchanged until complete	98%
Bands to use	All bands
Minimum members in a class	0.001%
Maximum Standard Deviation for a class	2.5
Minimum distance between class means	1.2

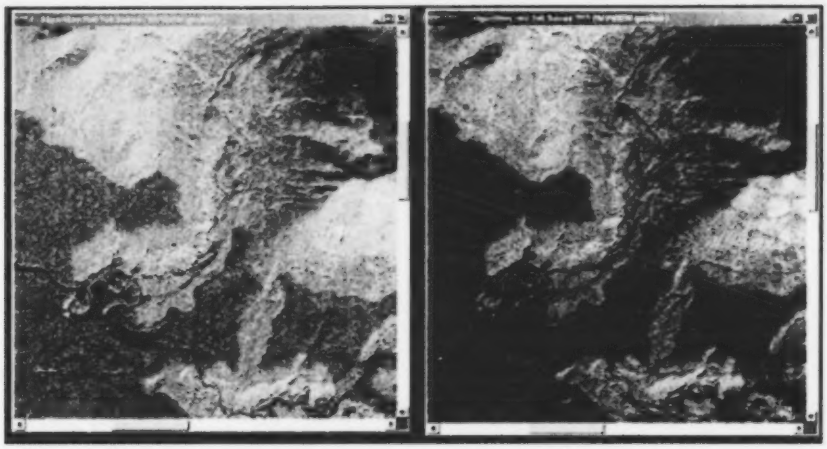

Figure 10. Natural colour image of a clearcut area (left) and the cluster analysis image of the same area.

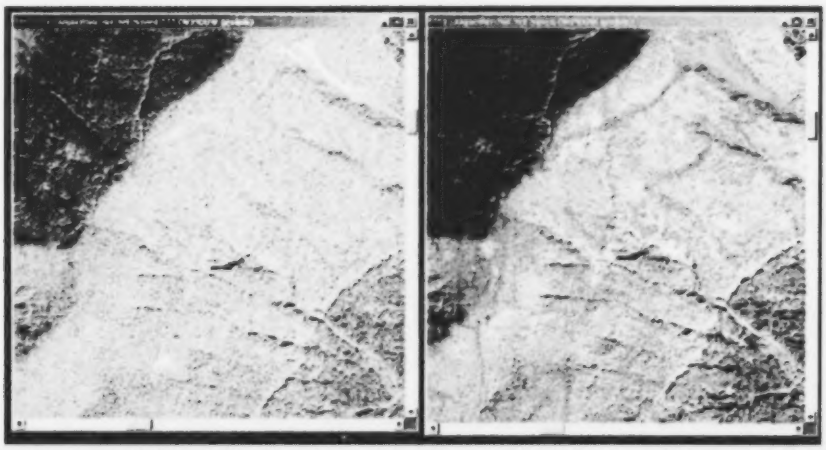

Figure 11. Natural colour image (left) and cluster analysis image of an area showing a landslide and the effects of shaded slopes.

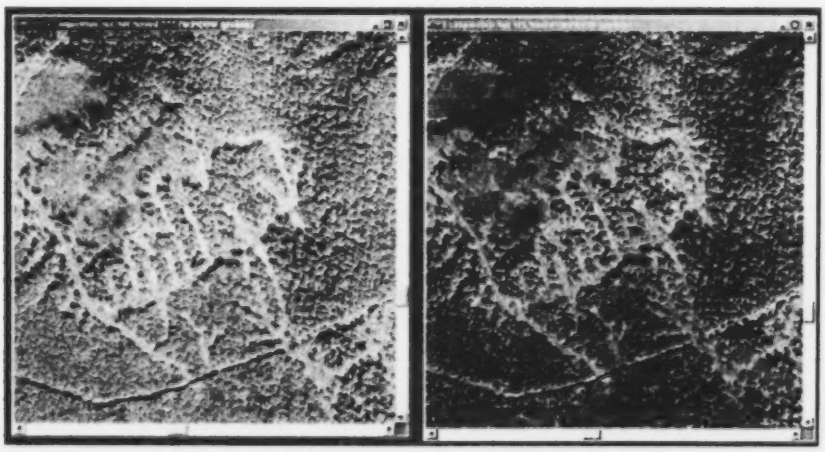

Figure 12. Natural colour image of a VR block (left) and the cluster analysis image of the same area.

Table 6. Change detection statistics; IK = Ikonos, 2000 image, QB = Quickbird, 2003 image.

Covariance Eigenvectors	PC1	PC2	PC3	PC4	PC5		PC7	PC8
Band1-IK-blu	0.05153	-0.05867	-0.13605	-0.38009	-0.03706	-0.27914	0.3284	-0.80236
Band2-IK-grn	0.10204	-0.1367	-0.20736	-0.55735	0.04224	0.10379	0.58191	0.51584
Band3-IK-red	0.10972	-0.13701	-0.2234	-0.60366	-0.10682	0.10386	-0.72976	0.01103
Band4-IK-nir	0.53432	-0.76379	-0.16258	0.31952	0.03901	-0.00822	0.00183	-0.03182
Band5-QB-blu	0.03298	0.12219	-0.32641	0.08169	-0.04354	-0.88395	-0.10086	0.27809
Band6-QB-grn	0.10631	0.27292	-0.53171	0.10734	0.75779	0.18673	-0.04703	-0.09303
Band7-QB-red	0.07331	0.24713	-0.61513	0.23442	-0.63631	0.28963	0.09257	-0.05359
Band8-QB-nir	0.81953	0.4746	0.30742	-0.07239	-0.05369	-0.0184	0.00529	0.01116

Red - PC4; Green - PC6; Blue - PC3

From the cluster analysis image (Figures 10, 11, 12), the shading effect from the mountains is evident. There are many shadowed classes, which causes cover types that are the same between the shaded and unshaded areas to be placed in separate classes. A lengthy process of labeling each of these classes as a particular cover type is required. Based on a visual comparison between this information product and the PCA colour composite image, more information can be derived from the PCA image. More subtleties are evident in the PCA image, and the PCA image does not show the problem of shadows, as the shadows have been assigned into a non-informative PCA channel for this analysis.

3.0 CHANGE DETECTION

3.1 CHANGE DETECTION INTERPRETATION

Upon detection of change in the multi-date imagery, the reasons for the change need to be determined. Areas of change due to clearcut harvesting were easily identified. However, smaller changes such as selective harvesting and variable retention were also detectable. The signature of the harvested areas provided insight into other more subtle changes along the margins of pre-existing harvested blocks, or in areas of standing timber or along road right-of-ways. Areas of regeneration were also detected on the change imagery, and some of these were not readily apparent on the natural colour imagery.

Visual interpretation of the change image was conducted using local knowledge and expertise, and ground truthing was also conducted to verify initial interpretations, to resolve anomalies, and to conduct onsite review and measurement of site-specific items.

3.2 CHANGE DETECTION USING PCA

In earlier phases of this project (Collins et al., 2001, and Kliparchuk and Collins, 2003), it was determined that Guided PCA is a highly useful image analysis technique for the monitoring and differentiation of forest resource features and anomalies. For the current phase, Guided PCA was chosen as a tool to help locate areas of change between the Ikonos and Quickbird images (Table 6). These images have near anniversary dates, and are three years apart. Other methods of change detection could have been used, such as simple image differencing, but the effects of shadows would need to be taken into consideration in matching the image histograms. Also, PCA is insensitive to differences in offsets/gains from each satellite sensor.

This particular band/colour combination was chosen because it resulted in an RGB image where newly exposed areas are yellow-red and newly regenerated areas are green-blue. Areas with relatively little or no change are shown in purple tones (Figure 13).

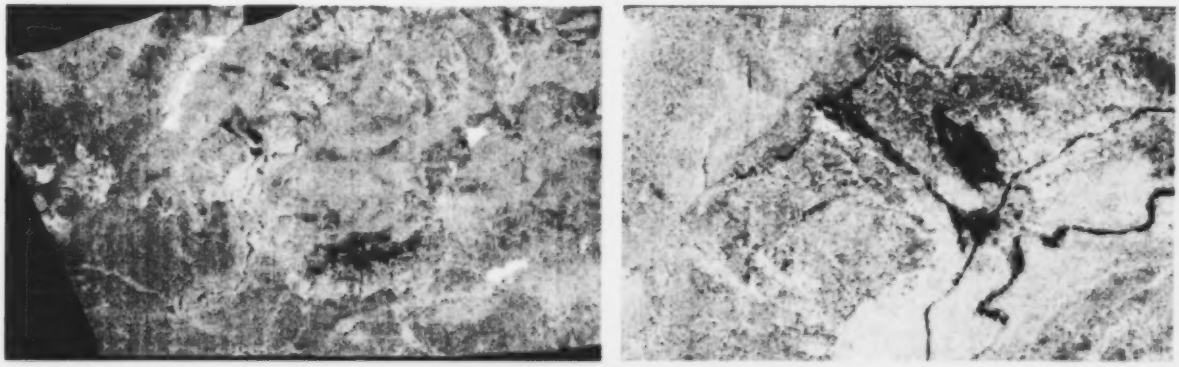

Figure 13. PCA colour composite change detection image. At right is an enlarged portion of the image. Revegetated roads are shown in cyan.

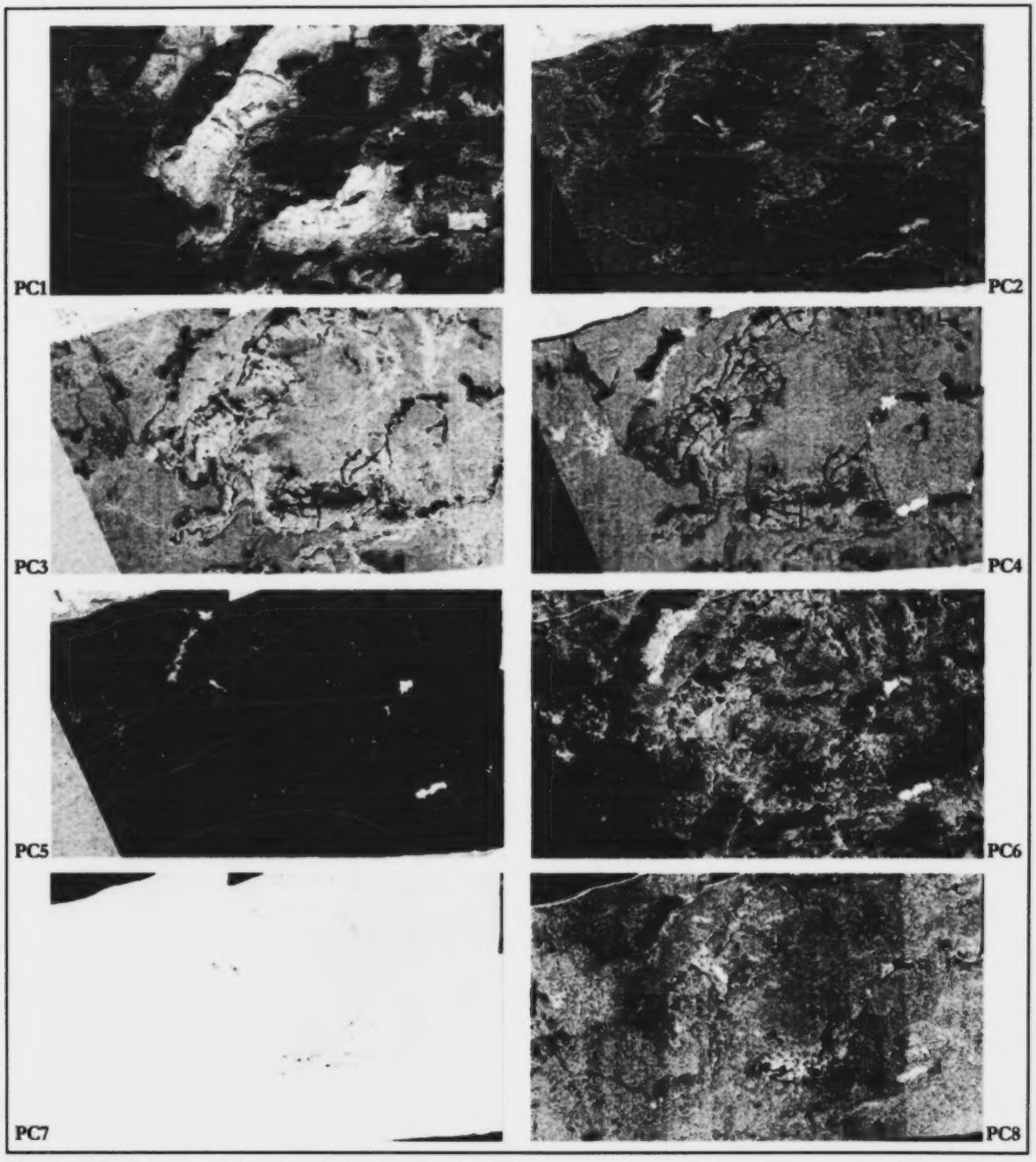

Figure 14. PC image bands 1-8 from the change detection image.

Ground truthing confirmed that the areas shown in cyan are revegetated with abundant alder, whereas the roads shown in dark green are sparsely revegetated with grasses and planted conifers in places. The roads represented in cyan in this image are difficult to delineate on the natural colour image, which makes the PCA change image analysis technique particularly useful for determining the effectiveness of revegetation efforts following road deactivation. The headscarp area of the large slide denoted by bright green/yellow is actively ravelling. Areas shown in black denote areas of no change.

The eight individual PCA bands from the change detection image are shown in Figure 14.

One VR block was mapped in detail in an earlier report by the authors using Ikonos imagery. The Quickbird image covered the same VR block three years later. Figure 15 shows the two dates of imagery and the PCA change detection image.

3.3 VEGETATION VIGOUR

An attempt was made using two different techniques to show an increase/decrease in vegetation vigour between the two dates of imagery. By default, these images also showed change detection. The two techniques applied were:

1. Differencing the near infrared channels, and
2. Generating a pseudo-ratio using the two infrared channels as input.

For the image differencing technique, the histograms from both dates were reviewed. In order to make sure that the vegetation parts of the histograms were subtracted for both dates, the upper and lower brightness values in the histograms were located and one image's contrast was linearly stretched so that the histogram ranges matched. It was assumed that the brightest and darkest features were the same or very similar features in both images.

A pseudo-ratio was generated by producing PC2 from a two-channel input image (Table 7). The two input channels in this case were the two near infrared channels from both the Ikonos image and the Quickbird image. While PC1 is typically the average of input channels, PC2 is the difference between the input channels. The forest-clearcut statistics were used to generate the PC2 pseudo-ratio. Samples of these two output images are shown in Figure 16. The pseudo-ratio images are on the left side and the image differencing image is on the right side.

The second and third images have lakes, and assuming that the lakes have not changed, the colour of the lakes should represent "no change". In general it appears that the pseudo-ratio shows more areas of no change in vegetation vigor than the difference image. The first and third images have north and south facing slopes. In the pseudo-ratio images, the north facing slopes tend to show more no change than the difference image. Areas with increased vegetation vigor, either due to actual vigour change in existing vegetation or a change from unvegetated to vegetated surface, are shown in red. The difference image appears to show more areas of increased vegetation vigour.

Table 7. Statistics for generating a pseudo-ratio using the two infrared channels. IK = Ikonos, QB = Quickbird.

Covariance Eigenvectors	PC1	PC2
IK-IR	0.543424	-0.839458
QB-IR	0.839458	0.543424

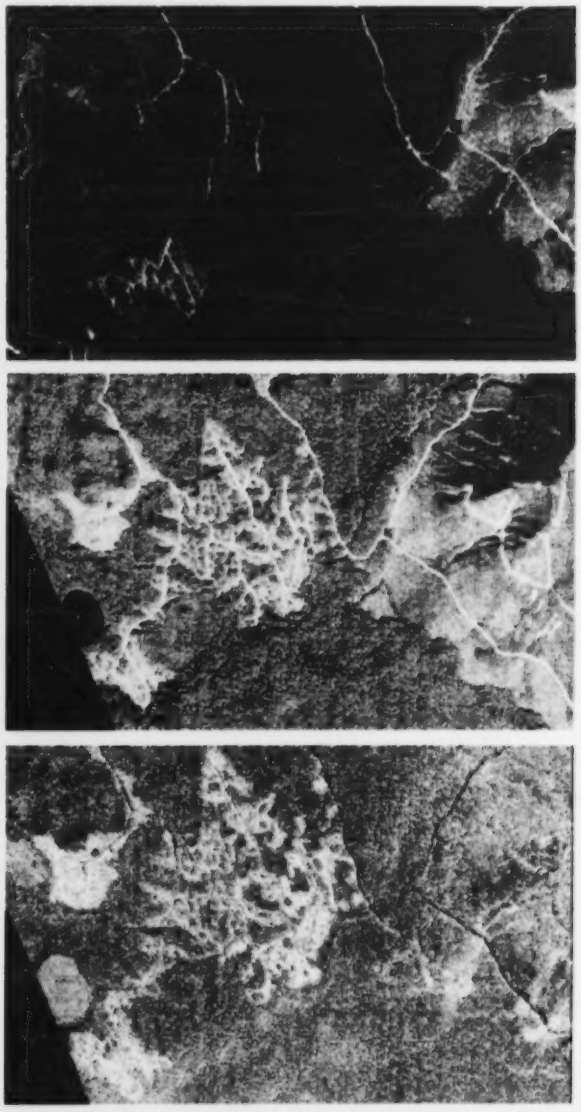

Figure 15. Three images of the same VR block. Top is Ikonos image showing a VR block in the bottom left corner. Centre is the Quickbird image of the VR block. Bottom view is the PCA change detection image showing new VR block.

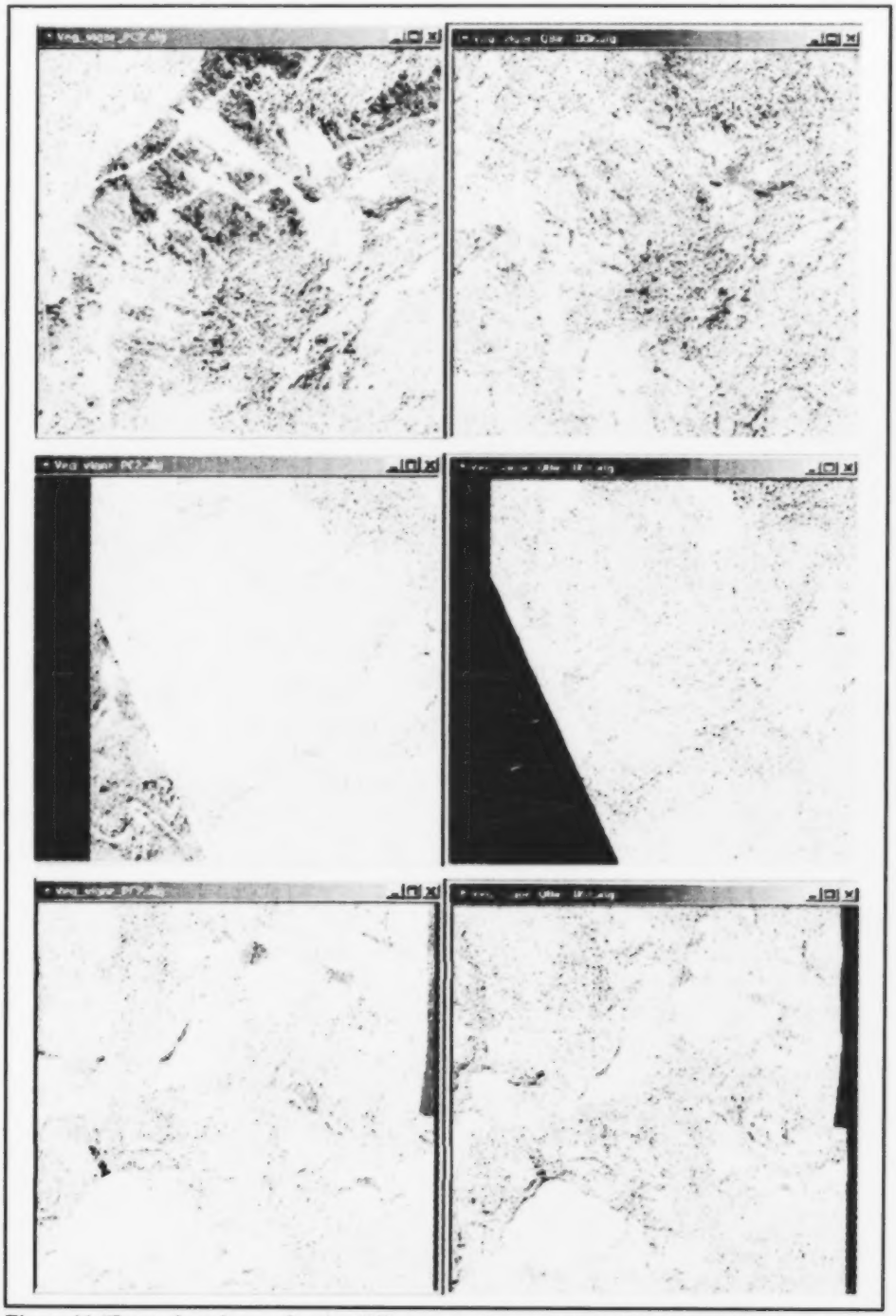

Figure 16. Three selected areas showing differences in the vegetation vigour images. The pseudo-ratio is shown on the left and the image difference is shown on the right. Red indicates increased vegetation vigour; yellow indicates no change in vigour.

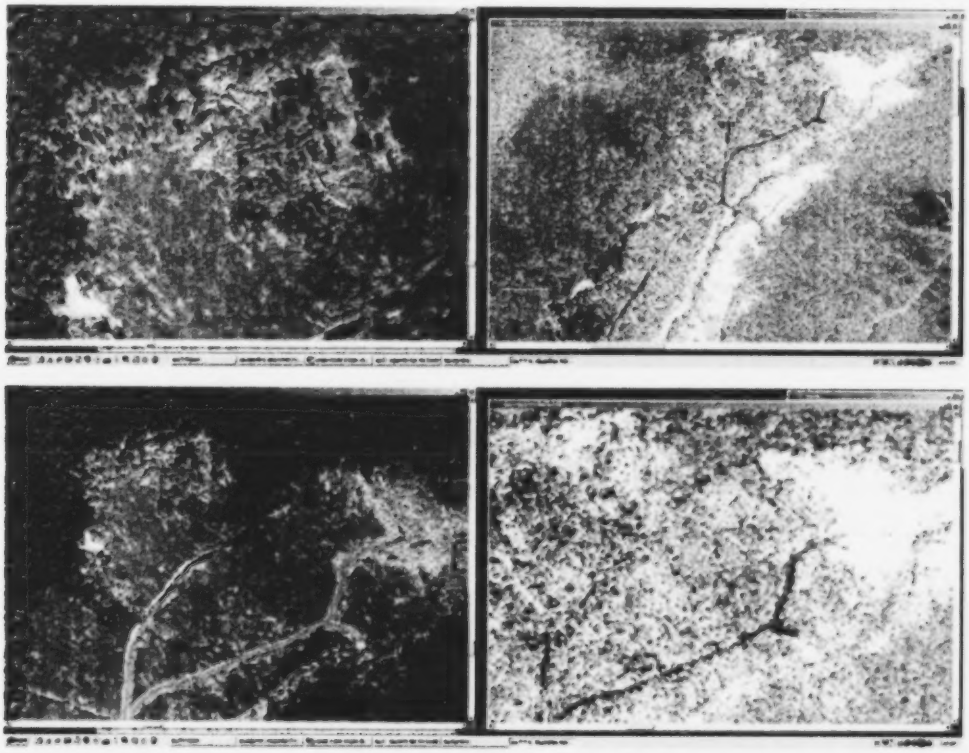

Figure 17. Quickbird false colour IR composite on left, PCA change detection image on right. Bottom pair is a closeup of the northeast corner of cut block, illustrating the colour scheme for vegetation transition as represented on the PCA image: yellow is new bare soil, green is exposed with some regrowth, blue is exposed with more regrowth.

3.4 WINDTHROW

The west coast of Vancouver Island is exposed to Pacific frontal storms, predominantly from the southeast, of high intensity and long duration, which can lead to patches of windthrown timber in some areas. The change detection image highlighted areas of new harvesting in yellow, and also more subtle areas with similar signatures along the margins of previously harvested blocks or within standing timber. The areas along the margins of blocks were interpreted as windthrow, and this was confirmed by ground-truthing (Figure 17).

Two polygons – Polygon 1, showing clearcut, and Polygon 2, showing variable retention – were selected for windthrow analysis (Figure 18). Potential windthrow was digitized from the natural colour imagery, and the orientations were plotted as full-circle rose diagrams with orientation proportional frequency and with the azimuthal field divided into 10° intervals. Polygon 1 had 344 data points and Polygon 2 had 151 data points digitized. In the rose diagrams, the longer the bar, the more downed timber is oriented in that direction (Figures 19, 20).

In Polygon 1, the dominant orientation of the downed timber is in a northeast-southwest (040°/070° – 220°/250°) trend, which given the location of the cutblock is indicative of a wind flow from the southwest. It is possible that this orientation of downed timber is due to wind turbulence along the leeward slope of the valley, or that the wind was at an oblique angle to the slope. The other data peak is in a northwest-southeast (130°/150°–310°/330°) direction.

Figure 18. Location of Polygon 1 and Polygon 2.

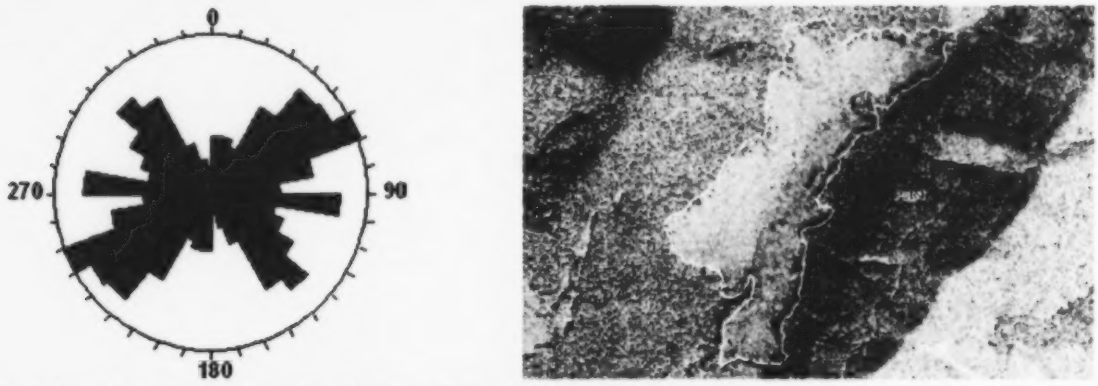

Figure 19. Polygon 1 downed timber orientation (rose diagram) and associated image area.

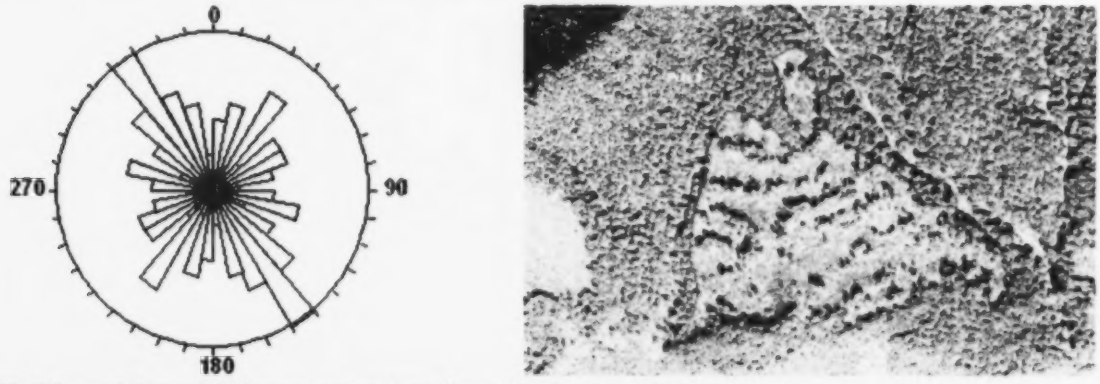

Figure 20. Polygon 2 downed timber orientation (rose diagram) and associated image area.

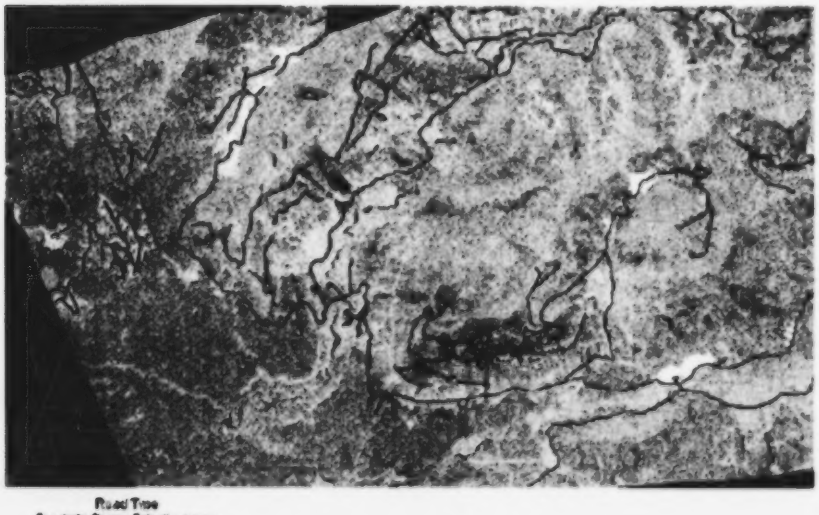

Figure 21. Road network digitized from change detection image.

In Polygon 2 (Figure 20), the dominant orientation is in a northwest-southeast direction (140°/150°–320°/330°), with a subdominant trend in a northeast-southwest direction, which corresponds with the dominant trend in Polygon 1.

3.5 ROAD INFRASTRUCTURE

The change detection image also highlights changes in the road infrastructure in the area of interest. Roads within the area of the change detection image were digitized and labeled according to their type of change (Figure 21). The following are the findings:

Total length all roads:	90662m
Length unchanged road:	86240m
Length of road reverted to vegetation cover:	2556m
Length vegetated cover converted to new/open road:	217m

Road width measurements determined from the imagery and ground truthing were found to be close approximations, with variations attributable to the difficulty of choosing the exactly corresponding ground truth locations on the imagery. Concrete bridge structures could be readily identified and delineated on the imagery (Figure 22) and on the ground, and the measurement of these structures was accurate to within one metre.

However, with respect to road widths, note the pixel size difference in Figure 23 between QuickBird (left) and Ikonos (right) images. It appears that the Ikonos 1 m resolution image may make roads appear wider due to the brightness difference between road and trees. Roads appear narrower in the QuickBird 61 cm image.

4.0 CONCLUSIONS

The Forest and Range Practices Act and its regulations establish the rules that govern commercial forestry and range activities on Crown lands, to ensure sustainability for future generations. In addition to the C&E regime, government and industry are committed to effectiveness evaluations to ensure that these legislated requirements and objectives are themselves effective and comprehensive. Therefore, the demand for timely and accurate resource feature information about the distribution, composition and status of landform features is likely to increase. It is envisioned that high-resolution satellite imagery

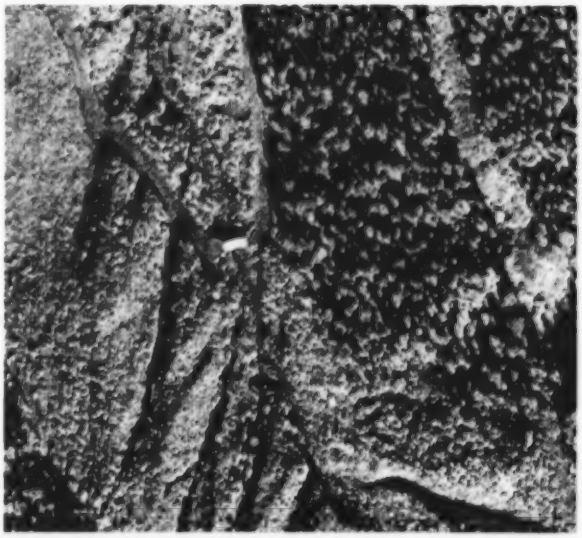

Figure 22: Z1 concrete bridge deck in ZuchIardi watershed.

will be one of the tools used by specialists reviewing on-the-ground results against objectives, so that government can monitor and improve its policies and objectives based on scientific data. Currently, some licensees and consulting firms are eager to adopt this technology to ensure they also base their resource management decisions on reliable data.

As part of an ongoing project in the Coast Forest Region, commercially available high-resolution satellite imagery has been shown to be capable of differentiating small-scale forest resource features (Collins et al., 2001, and Kliparchuk and Collins, 2003). Image analysis methods such as PCA and change detection have also been shown to be useful techniques for forest resource management and for input to C&E risk analysis and priority setting activities. Change detection using high-resolution imagery enables subtle changes to be recognized along cut block boundaries, and allows the monitoring of changes in veg-

Figure 23. Road width differences in images (Quickbird image on left, Ikonos image on right).

etation vigour and regeneration in harvested blocks, along deactivated roads, and on rehabilitated landslides.

From an effectiveness evaluation perspective, information on the status and trends of vegetation regeneration, wildlife habitat areas, riparian zones, landslide activity, and some channel processes can be determined using imagery and image analysis techniques such as PCA. In addition, change detection analysis over time should be an important issue for state of the forest reporting.

From a cost/benefit perspective, high-resolution satellite imagery is best suited for areas of high-priority interest for forest resource managers and C&E staff. The capability to select and manipulate the multi-spectral bands is an important feature that satellite imagery offers in contrast to standard aerial photography. However, aerial photography is less expensive for large area coverage, and for non-time-critical mapping. The advantages of high-resolution satellite imagery for areas of high priority are that it is in a digital, orthorectified, mosaicked format, and is therefore Geographic Information System ready. In addition, it provides access to imagery covering the visible and near infrared portion of the spectrum, which allows the production of natural colour and false colour composite images. There is also the potential for better vegetation mapping due to the differences in vegetation response in the visible versus near infrared portions of the spectrum.

Strengths of high-resolution Quickbird satellite imagery:

- Provides good input for mapping, inventory, monitoring, surveying;
- Information is captured in digital format, plus it provides visible and NIR spectral information;
- Allows digital processing and interpretation;
- 11-bit data is better for shadowed areas.

Weaknesses of high-resolution Quickbird satellite imagery:

- High cost (US$ 30/km2 for black and white or colour);
- Minimum order size is 272 km2;
- Cloud cover (can be up to 20%);
- Need to order for a future date (for low demand areas).

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APPENDIX A: GROUND CONTROL POINTS AND RMS RESIDUAL ERROR REPORTS

North Image:

Point ID	ImageX	ImageY	East	North	Elevation	Residual	ResX	ResY
G0001	21707.75	14398.25	688561.9	5492869	602	2.26	2.22	-0.43
G0002	23589.75	6913.25	689667	5497385	459	5.21	4.43	2.74
G0004	23210.88	17008.13	689429.5	5491344	353	0.69	0.15	0.68
G0005	2674.81	15371.56	677054.9	5492382	31	4.58	1.16	-4.43
G0006	10920.13	11653.13	682092.7	5494521	563	2.46	1.99	1.44
G0007	16632.63	16812.88	685513.9	5491429	536	3.36	-3.27	0.73
G0008	8188.88	16723.38	680454.4	5491474	588	4.34	-4.28	-0.69
G0009	6431.88	11604.38	679413.7	5494529	689	0.46	0.44	-0.14
G0010	17473.88	11528.13	686003.9	5494620	415	5.29	4.13	3.31
G0011	19472.75	6825.25	687179.4	5497468	306	7.91	-4.77	-6.31
G0012	17148.69	3894.19	685747.7	5499273	22	6.21	-5.63	-2.62
G0013	7988.13	6366.63	680248.4	5497785	0	9.42	4.04	8.52
G0014	13513.25	3941.75	683624.8	5499176	427	2.81	-0.47	-2.77

South Image:

Point ID	ImageX	ImageY	East	North	Elevation	Residual	ResX	ResY
G0001	13642.88	25264.38	683642.4	5479813	0	4.45	-1.42	-4.22
G0002	19128.88	17918.88	686941.6	5484212	38	1.6	-1.44	-0.69
G0003	25295.69	11218.56	690638.3	5488231	40	2.93	1.68	2.4
G0004	21371.94	3583.938	688359	5492721	602	3.52	-1.21	-3.3
G0005	17426.75	14418.25	686022.5	5486179	812	3.92	1.69	3.54
G0006	12015.25	13596.25	682744.5	5486715	570	4.18	-3.52	2.25
G0008	12234.25	7572.25	682890.9	5490323	639	5.93	2.59	-5.34
G0009	21253.63	7905.125	688256.4	5490163	361	6.27	-3.17	5.42
G0010	25965.38	20276.38	691086.9	5482722	479	3.76	3.7	-0.64
G0011	15657.13	10125.88	684876.9	5488868	169	5.78	-5.32	-2.26
G0012	9578.25	10260.75	681222.5	5488798	91	7.83	6.96	3.6
G0015	11211.25	18454.75	682222	5483849	278	2.13	-0.99	1.89
G0016	23211.13	5947.875	689429.4	5491344	353	2.64	0.57	-2.58